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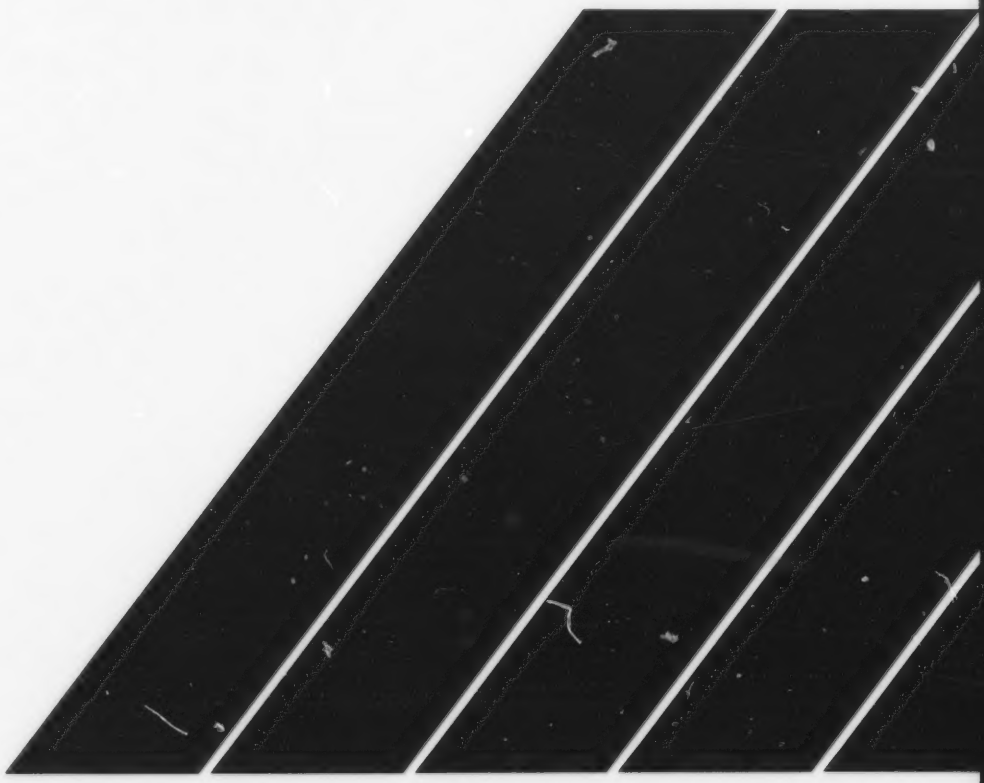

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COPPER IN GOLD PLANT EFFLUENT

(SASKATC[illegible]WAN MDA)

FINAL REPORT

BY

Cameco Corporation

Work on the project was conducted under the auspices of the Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources Canada. This work was supported in part by the Federal Panel on Energy R&D (PERD).

DSS FILE NO: 039SQ.23440-1-9091
DSS CONTRACT SERIAL NO: 23440-1-9091/01-SQ
CANMET PROJECT NO:
CANMET SCIENTIFIC AUTHORITY: Dr. P. Riveros
DATE: May, 1992

49 pp

MICROMEDIA

93-01567/

EXECUTIVE SUMMARY

Natural degradation processes, as used at the Star Lake waste management facility for gold mill tailings , effectively removed cyanide during the open water season but were unable to reduce apparent dissolved copper concentrations to below effluent release compliance levels. This study was undertaken for the purpose of examining the causes of the problem and investigating possible mitigative measures based on an understanding of these causes. The testwork program included chemical characterization, pure chemical precipitation, filtration, coagulation, natural degradation, microbiological enumeration and tests on natural lake sediments to investigate colloid formation. A number of conclusions and recommendations are made, pertinent to the design of future gold mill waste management facilities where the intention is to use natural degradation. Of particular significance is the finding that organic materials occurring in natural lake sediments greatly enhance the rate of cyanide decomposition (probably through biological mechanisms) however, the associated fine solids appear to adsorb and stabilize copper in the form of slow or non-settling colloids which report as dissolved copper under standard laboratory analysis procedures. The results of the study suggest that standard coagulation/thickening and filtration processes can be used to physically remove residual copper as opposed to oxidation processes aimed at chemically destroying the colloidal solids.

RESUME EXECUTIF

Les processus naturels de dégradation tels ceux utilises à Star Lake dans l'installation pour le maniement de déchet des refus du moulin à l'or, ont effectivement dispersé le cyanure pendant la saison dont l'eau coule mais etaient inaptes à reduire l'apparente concentration de cuivre plus bas que le niveau acceptable pour le dégagement de l'effluent. Cette etude à été entreprise dans le but de rechercher les causes du probleme et pour examiner des mesures moderees basees sur l'entendement de ces causes. Les programs de tests ont inclus la caraterisation chimique, precipitation de chimique pure, filtration, coagulation, dégradation naturelle, enumeration microbiologique, et des tests sur les sédiments naturels lacustres pour examiner des formations colloidales. Un nombre de conclusions et de recommendations sont faits, pertinent au modèle d'installation future pour le maniement de déchet du moulin à l'or ou l'intention est d'utiliser la dégradation naturelle. De grande significance est le fait que la matière organique qui fait part des sédiments naturels lacustres augmente considerablement le taux de décomposition de la cyanure (probablement par des mécanismes biologiques) cependant, les aliments solides associes apparaissent d'absorber et de stabiliser le cuivre sous forme de colloides lentes à se former ou bien non-sédimentaires qui, sous les processus normaux d'analyses laboratoires, le resultat les indique comme cuivre dissous. Le resultat de l'etude suggère que la coagulation normale et les processus de filtration peuvent etre utilises pour enlever physiquement le cuivre residuaire par opposition aux processus d'oxidation vises à chimiquement detruire les solides colloidaux.

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1.0 INTRODUCTION

The Star/Jasper mill started operation in November 1986, processing ore from the Star Lake Mine. The natural degradation process removed cyanide effectively during the summer months but was not able to reduce copper to comply with discharge standards. To correct this situation an effluent polishing system consisting of spray irrigation and wetland treatment was started up in 1988 to treat tailings pond O/F. A study conducted to assess removal mechanisms and loading criteria for the wetland system concluded that adsorption and filtration were likely the major mechanisms responsible for treatment (Gormely et al, 1990). The data examined during the study indicated that copper was likely present in the tailings pond supernatant as a stable colloid, although accurate speciation of the copper was not possible based on the data available.

A plot of tailings pond characteristics spanning both the Star Lake and Jasper Operation is provided in Figure 1.1.

The data set includes information during the discharge period for the years 1989, 1990 and 1991. There was no mill discharge to the tailings pond between July 1989 and April 1990. During early 1989, the natural degradation process attenuated cyanide yielding a concentration less than 2 mg/L by mid-July. However the copper concentration in the pond supernatant did not drop in parallel but remained in the 5-10 mg/L range until the end of the summer season. Pond supernatant contained measurable levels of organic carbon (16 - 17 mg/L) and suspended solids concentrations were also relatively high (i.e. 90-139 mg/L) during this period. Ammonia levels were in the order of 18-20 mg/L N.

The Star Lake orebody was exhausted in early 1989 and the mill was shutdown in June 1989. However the copper concentration in the pond supernatant stayed in the 3-5 mg/L range through the 1990 summer season even though the cyanide concentration remained very low.

Gormely, L., T.W. Higgs, R.U. Kistritz and A. Sobolewski. 1990. Assessment of Wetlands for Gold Mill Effluent Treatment. Prepared by Gormely Process Engineering for Mines Pollution Control Branch, Saskatchewan Environment and Public Safety.

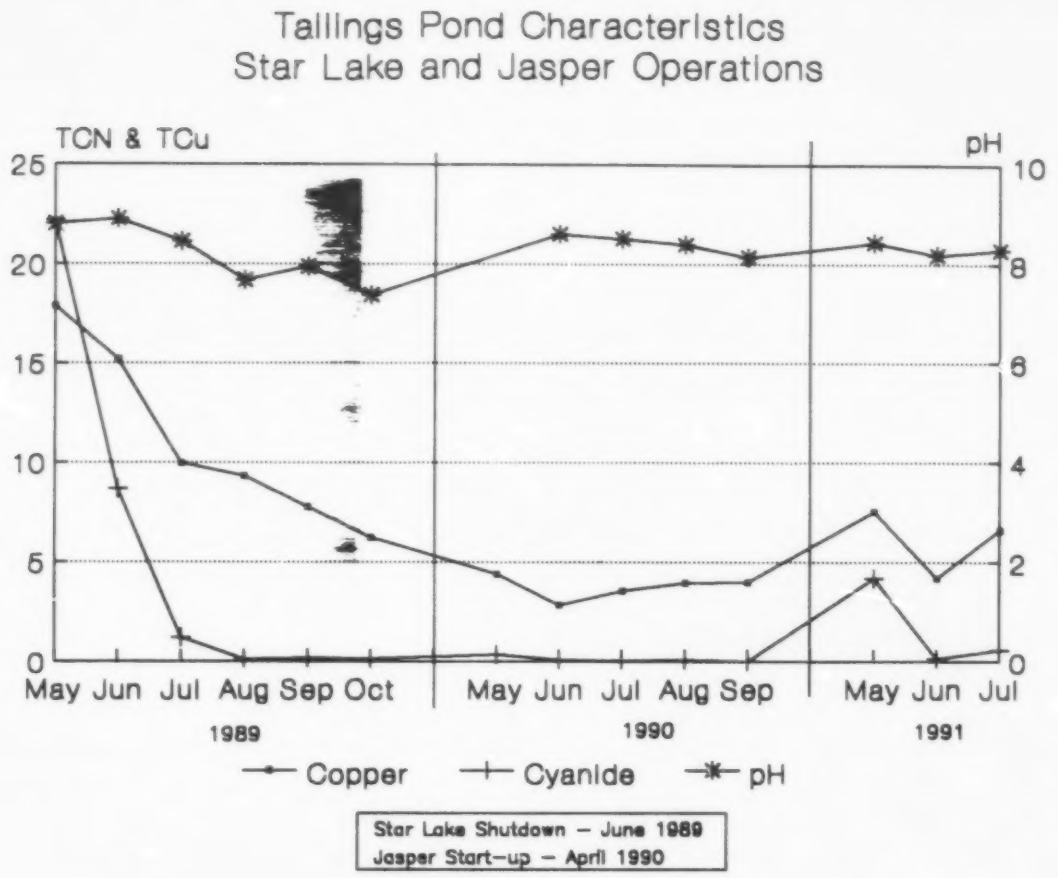

Figure 1.1
Tailings Pond Characteristics Star Lake - Jasper Operation

The mill was reactivated and start-up again in April 1990 to process ore from the Jasper Mine. In the spring of 1991, the concentrations of cyanide and copper in tailings pond supernatant were significantly less than that experienced during the Star Lake operation. After the ice cover melted from the pond, TCN in the supernatant was about 4 mg/L compared to 22 mg/L in May 1989 during Star Lake. Copper in the tailings pond supernatant remained in the 2-3 mg/L range during the 1991 season. One of the major differences between the Star Lake and Jasper operations may have been the quantity of cyanide discharged to the pond from the mill. A plot of mill effluent characteristics for Jasper operation is provided in Figure 1.2. Mean TCN concentration of mill effluent during this period was about 150 mg/L compared to TCN concentrations in the 300-350 range during the Star Lake Operation.

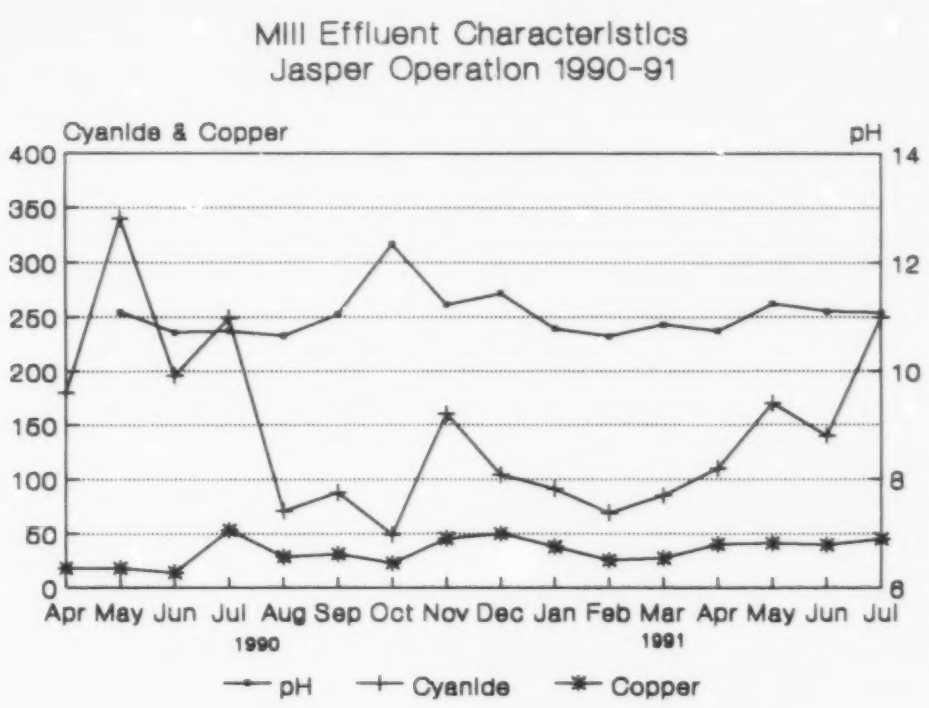

Figure 1.2
Mill Effluent Characteristics - Jasper Operation

However up until the Jasper Operation was shutdown in December 1991 the copper concentration in tailings pond supernatant remained above discharge standards in the 2-3 mg/L range. The sample of reclaim water collected as part of the testwork program described in Section 2.0 contained 1.42 mg/L total copper and 0.392 mg/L dissolved copper. The concentration of copper in true solution in this sample was only marginally greater than theoretical solubility based on the measured cyanide concentration (i.e. 0.15 mg/L). These concentrations were significantly less than experienced during the Star Lake Operation.

Since the initial plan for this project was to use actual samples from the Jasper Operation tailings pond to evaluate the chemistry and behaviour of copper, it became necessary to modify the plan to use simulated samples.

2.0 TESTWORK PROGRAM

2.1 Outline

In order to evaluate the behaviour of copper in gold mill effluent a series of bench tests were conducted as described below. Tests conducted were as follows:

1) Chemical characterization of mill tailings filtrate, reclaim water, final discharge and lake sediments samples to provide background data to support the testwork program.

2) Pure chemical tests to investigate the precipitation of cupric and cuprous ions using carbonate, phosphate and hydroxide anions.

3) Filtration tests to determine if "dissolved" copper was present as a colloid that could be removed by filtration.

4) Coagulation tests to evaluate the ability of standard coagulants to remove colloidal copper from the reclaim water sample.

5) Lake Sediment tests conducted to evaluate the ability of the lake sediments to extract cupric ion and copper cyanide complex from solution and form stable colloids that would report as "dissolved" copper.

6) Natural degradation studies to evaluate the formation of soluble and colloidal metal complexes during the natural degradation process.

7) Microbiological tests using the Natural Degradation samples to enumerate the concentration and morphology of organisms capable of degrading the copper cyanide complex.

2.2 Description of Samples

The following samples were collected during the site visit to assist in conducting the testwork.

1) Mill Tailings Filtrate

2) Reclaim Water

3) T3 O/F

4) Lake Sediments

The analytical results for these samples are provided in Appendix A (ASL File 8239B).

The mill tailings filtrate reported dissolved copper of 46.3 mg/L and TCN of 86.5 mg/L. Dissolved copper was assumed present as the copper cyanide complex $Cu(CN)_3^{-2}$. In addition to copper cyanide, the mill tailings filtrate also contained some nickel (0.288 mg/L Ni) and zinc (1.45 mg/L Zn) that was assumed complexed with cyanide. Based on

a balance between cyanide and metal it would appear that the mill tailings filtrate contained approximately 25 mg/L of "free cyanide".

The reclaim water contained total and dissolved copper concentrations of 1.42 and 0.39 mg/L respectively while TCN was 0.123 mg/L. The reclaim water contained an appreciable concentration of suspended solids (389 mg/L) due to the presence of "slimes" in the tailings. All water sample analyses followed procedures described in "Standard Methods" (1). The metal content of water samples was determined by atomic absorption spectrophotometry. Sediments samples were digested using a combination of nitric and hydrochloric acids. The resulting extract was bulked to volume with deionized/distilled water. The digested portion was then analyzed by atomic emission spectrophotometry. The dissolved metals procedure used 0.45 μm filtration followed by acid digestion of the filtrate.

T3 O/F is the final discharge point in the waste management system. This sample had a pH of 5.53 and contained 0.043 mg/L TCN and 0.065 mg/L dissolved copper.

The lake sediment sample analyzed contained 12.4% dry solids on a wet weight basis. The dried lake sediments contained 12% organic carbon. The metals present consisted of significant amounts of aluminum, iron, calcium and magnesium (1.34, 1.26, 0.88 and 0.54% respectively). Copper content was 64.2 mg/kg dry weight.

2.3 Pure Chemical Tests

The purpose of the pure chemical tests was to investigate the precipitation of cupric and cuprous ions using carbonate, phosphate and hydroxide anions.

Attempts were made to produce solutions containing cuprous ion (Cu I) using cuprous chloride. However cuprous chloride did not dissolved readily in distilled water. Approximately 24 hours of mixing was provided. The cuprous ion was, however, found to oxidize rapidly to cupric ion even using de-aerated distilled water. The presence of cupric ions in the cuprous chloride solution was detected using an ammonia spot test. The addition of ammonia to a solution containing cupric ion results in the formation of a blue coloured complex while ammonia addition to a solution only containing cuprous ions does not. All solutions of "cuprous chloride" that were produced turned blue on addition of ammonia. Additional work with cuprous ion was abandoned due to the difficulty in producing a stable cuprous chloride solution that could be handled under standard lab conditions.

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(1) Standard Methods for the Examination of Water and Wastewater" 17th Edition published by the American Public Health Association, 1989

A solution containing cupric ion was generated by dissolving cupric sulphate pentahydrate in distilled water to yield a solution containing approximately 20 mg/L Cu^{+2}.

Three anions were investigated for the precipitation of cupric ions, namely carbonate, phosphate and hydroxide using sodium carbonate (soda ash), sodium phosphate and calcium hydroxide (hydrated lime).

The initial copper concentration of the Cu (II) solution was 21.4 mg/L and initial pH was 4.41. Sodium carbonate, sodium phosphate and calcium hydroxide solutions were added to aliquots of the Cu (II) in three separate tests. 1 hour after the addition of reagents, 300 mL aliquots from each sample generated in this series of tests, were filtered through 0.45 μm filter paper and were digested and analyzed for copper using a Hach Spectrophotometer. A duplicate set of filtrates were analyzed by ICP to confirm the results obtain using the spectrophotometric method.

2.3.1 Sodium Carbonate Test

6.5 mL of 0.5 % soda ash solution were added to 500 mL of the Cu (II) solution to generate a Na_2CO_3 concentration of 65 mg/L. pH increased to 8.67. The solution initially turned pale blue and then faded. After 10 minutes, pH had increased further to 9.1 and a noticeable blue floc formed. The carbonate test generated a dissolved copper level of 0.04 mg/L and produced a blue precipitate. The filtration rate was fast.

2.3.2 Sodium Phosphate

6.5 mL of 0.5 % $Na_2HPO_4 \cdot 2H_2O$ was added to 500 mL of the pure Cu (II) solution. The pH of the Cu (II) solution decreased to 4.31 without formation of a precipitate. The pH was then increased to 10 using NaOH. The solution turned blue and faded as above. The phosphate test generated a dissolved copper level of 0.31 mg/L and produced a blue precipitate. The supernatant remained cloudy and the filtration rate was slow.

2.3.3 Calcium Hydroxide

2.1 mL of hydrated lime slurry containing 15 mg/mL $Ca(OH)_2$ was added to 500 mL of the Cu (II) solution. The pH initially increased to 11 and a white floc formed. Final pH prior to filtration was 10.8. The hydroxide test generated a dissolved copper reading of 0.01 mg/L and the filter paper was greenish brown.

The results of the pure chemical tests are plotted in Figure 2.1. The results indicate that both soda ash and lime effectively precipitated cupric ion from solution while phosphate was not as effective. Both soda ash and lime produced precipitates that settled well and did not report as "dissolved" copper. Phosphate addition however produced a cloudy supernatant and a poor settling fine precipitate. The supernatant remaining after the

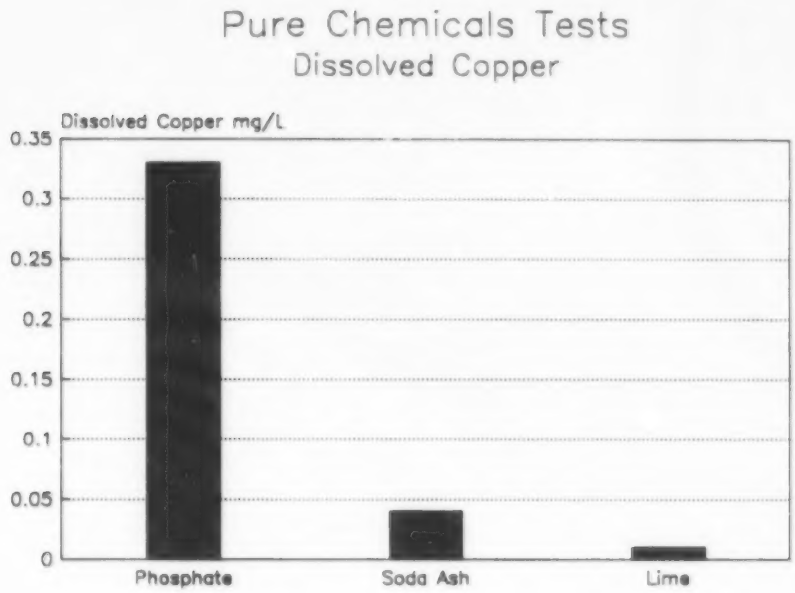

Figure 2.1
Pure Chemical Tests

solids were allowed to settle in the phosphate test, filtered very slowly and contained particles that reported as "dissolved" copper after 0.45 μm filtration.

2.4 Filtration Tests

Reclaim water was filtered in triplicate through three grades of filter paper: 1.2 μm, 0.45 μm and 0.22 μm using 300 mL samples. The filtrates were analyzed for total copper using a procedure that involved acid digestion and analyses using a spectrophotometric method. Filtration rates were considerably slower using smaller pore size filter paper.

The purpose of this test was to determine if "dissolved" copper was present as a colloid that could be removed by filtration. Based on the measured cyanide concentration of 0.123 mg/L, the quantity of copper theoretically complexed with cyanide would be 0.101 mg/L assuming copper is present as $Cu(CN)_3^{-2}$. Based on a measured "dissolved" copper concentration of 0.392 mg/L, the reclaim water contained an excess of 0.291 mg/L copper in apparent solution above that predicted by the presence of copper

cyanide complex. The solubility of copper as a hydroxide at the measured pH of 7.64 would theoretically be 0.07 mg/L, while the solubility of copper as $CuCO_3$ would be less than 0.05 mg/L if the carbonate concentration is greater than 30 mg/L as $CaCO_3$. The alkalinity of the reclaim water was 172 mg/L as $CaCO_3$.

The filtrate copper concentration using 1.2 μm paper was 0.343 mg/L while the filtrate readings for 0.45 μm paper and 0.22 μm paper generated similar copper readings of 0.336 and 0.340 mg/L respectively.

Microscopic examination of the filtrates indicated that some of the samples contained a few particles between 0.10 and 0.01 μm. However the microscopic results were not definitive in that it was difficult to draw any correlation between the "dissolved" copper results and inspection of the individual slides. All filter papers were a grey colour due to the presence of slimes in the raw sample. The filtration tests indicated that if copper was present in the sample as a colloid its particle size was less than 0.22 μm. This result is supported by data collected during the natural degradation test.

2.5 Coagulation Tests

The purpose of the coagulation tests was to evaluate the ability of standard coagulants to remove colloidal copper from the reclaim water. The reagents tested were lime, alum, ferric sulphate and a combination of lime and soda ash. A polyelectrolyte (Percol 156) was added in each case to flocculate the samples and precipitate suspended solids prior to filtration.

2.5.1 Ferric Sulphate

The initial pH of the reclaim sample was 6.88. 1 mL of a ferric sulphate solution containing 37 mg Fe^{+3}/mL was added to 500 mL of reclaim water to yield a solution containing 74 mg/L Fe^{+3}. pH dropped to 2.54. The solution turned a red colour and floc formation was noted. 4 mL of 1.5 % $Ca(OH)_2$ (lime) slurry was then used to raise the pH to 5.8. A further addition of 0.5 mL of lime slurry raised the pH to 7.78. 2 mL of Percol 156 solution (0.5 %) was then added to flocculate the sample. The pH continued upward, finally equilibrating at 8.57. After 15 min. the supernatant was analyzed for turbidity, colour, plus total and dissolved Cu.

2.5.2 Alum

Alum solution was added to yield a concentration of 16 mg/L Al^{+3}. The pH decreased slightly to 6.53. Lime slurry was then added to increase pH to 7.57 followed by Percol 156 addition as above. Two mL of polyelectrolyte were added. After 15 min. the supernatant was analyzed for turbidity, colour, plus total and dissolved Cu. The sample retained a slightly cloudy appearance.

2.5.3 Lime

A 1.5% lime solution was added in two stages to raise pH to 10.37. Coagulation was poor. Percol 156 at 3 mg/L was added to improve clarity. Samples were analyzed as above.

2.5.4 Ferric Sulphate and Soda Ash

This test was a repeat of the ferric sulphate test (3.1) with the exception that soda ash was used in place of lime to adjust pH. Fe dosage was 74 mg Fe^{+3}/mL. Sodium carbonate solution was used to increase pH to 8.70. Percol 156 was added as before.

2.5.5 Lime and Soda Ash

A coagulation test was also performed using lime and soda ash in combination. 250 mg $NaCO_3$ was added to a 1 L aliquot of reclaim water increasing the pH from 6.80 to 10.33. This was followed by the addition of 20 mL of hydrated lime slurry containing 15 mg $Ca(OH)_2$/mL thereby increasing the pH to 11.83. A noticeable white floc formed. The sample was then coagulated with 2 ppm Percol 156 and filtered.

2.5.6 Results and Discussion

The results of the coagulation tests are summarized in Figure 2.2.

Ferric sulphate and lime was the least effective combination of the series tested in the removal of copper. The total copper concentration dropped from 1.42 mg/L in the raw reclaim sample to 0.38 mg/L in the supernatant, while dissolved copper dropped from 0.392 to 0.26 mg/L. However ferric sulphate was effective in the removal of colour and turbidity.

Alum was reasonably effective for the removal of total and dissolved copper from the reclaim sample but, not as effective as ferric sulphate either with lime or soda ash in the removal of colour and turbidity.

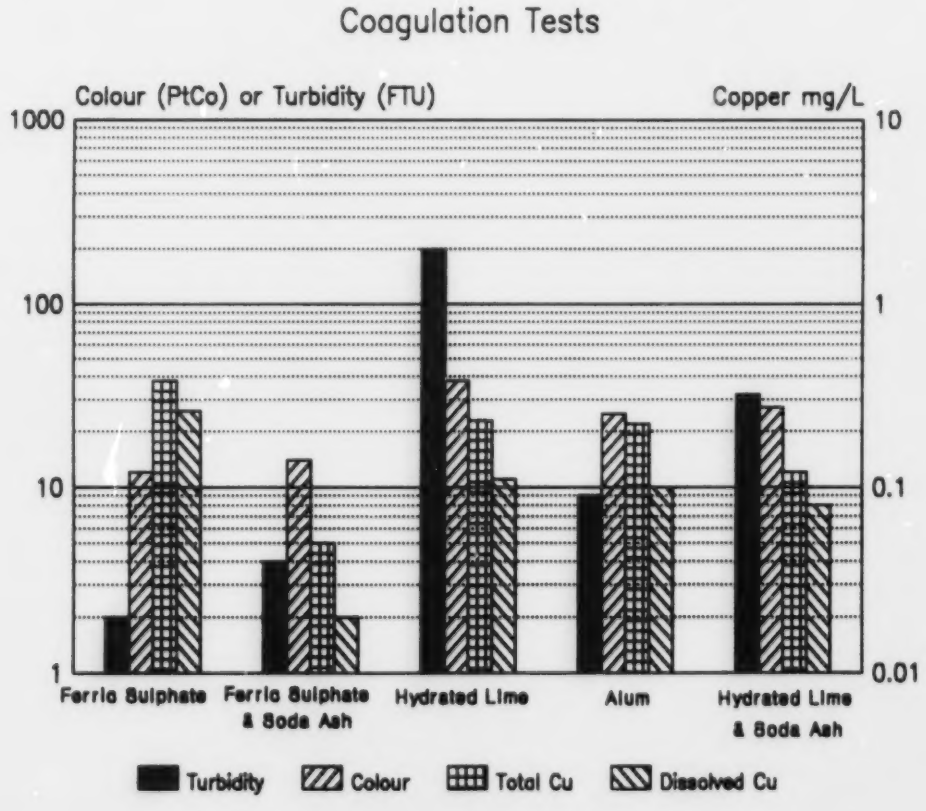

Figure 2.2
Coagulation Tests

Lime generated a supernatant with high turbidity and colour but reasonably low total and dissolved copper. Percol 156 may not have been effective in coagulation of the lime-treated sample due to its high pH.

Soda ash with ferric sulphate was the most effective combination of the series in the removal of colour, turbidity, total copper and dissolved copper. Total and dissolved copper levels were 0.05 and 0.02 mg/L respectively.

The combination of soda ash and hydrated lime produced lower values for turbidity, colour, total copper and dissolved copper than either straight lime or alum.

2.6 Lake Sediment Tests

Four separate tests were conducted to evaluate the ability of the lake sediments to extract copper and to form stable colloids that would report as "dissolved" copper. Test # 1 involved two runs using a suspension of lake sediments and copper sulphate solution. Test # 2 involved the reaction of lake sediments with a solution containing $Cu(CN)_3^{-2}$ and free CN. Test # 3 was similar to Test # 2, except it involved the reaction of lake sediments with a solution of copper sulfate without cyanide present. Test # 4 was a repeat of Test # 2 using lake sediments and $Cu(CN)_3^{-2}$ but without free CN present. Test # 4 is still proceeding at the time of writing.

2.6.1 Lake Sediment Test #1

2.6.1.1 Purpose

The purpose of this test was to determine if cupric ion would attach to fine colloidal matter in lake sediments and report as "dissolved copper" using standard 0.45 μm filtration for determination of dissolved copper.

2.6.1.2 Procedure

The solids content of the lake sediments sample was determined gravimetrically so as to standardize all tests on a dry weight basis. The sample contained 12.4% dry solids on a wet weight basis. The raw sediment sample contained a large amount of coarse solids including roots and grass. The sediments were screened to reduce testing variability using a Tyler #45 screen.

Twenty five grams of wet sediments were added to a 1L graduated cylinder. 10 mL of $CuSO_4$ standard solution were added to the suspension to produce a sample containing 20 mg/L copper. pH dropped to 5.7. 1 N NaOH was used to adjust the pH to 7.62. Sediments flocculated rapidly leaving a relatively clear supernatant. This sample was left overnight and the supernatant was then analyzed for turbidity, colour, total Cu and dissolved Cu. The results, designated as Run # 1, are plotted in Figure 2.3.

This procedure was repeated the next day with fresh sediments but only allowed 1.5 hr to settle. The results, designated as Run # 2 are plotted in Figure 2.3.

2.6.1.3 Results

The second run produced a supernatant with higher turbidity and total colour due to the difference in the length of time available for settling. Total copper was 2.05 and 5.50 mg/L in Run 1 and 2 respectively, indicated that the lower suspended solids level associated with the longer settling time resulted in a lower total copper since copper is apparently attached or incorporated into the particles. However in the case of dissolved copper the opposite correlation occurred. The dissolved copper in Run # 1 was 0.62 mg/L while dissolved copper in Run # 2 was 0.20 mg/L. This difference is potentially due to the formation of more stable colloidal copper in Run # 1 than Run # 2 that was not removed by 0.45 μm filtration. It should be noted that these samples did not contain cyanide which would normally be responsible for the presence of copper in samples at neutral pH reporting 0.62 mg/L "dissolved copper". However the sediments will contain

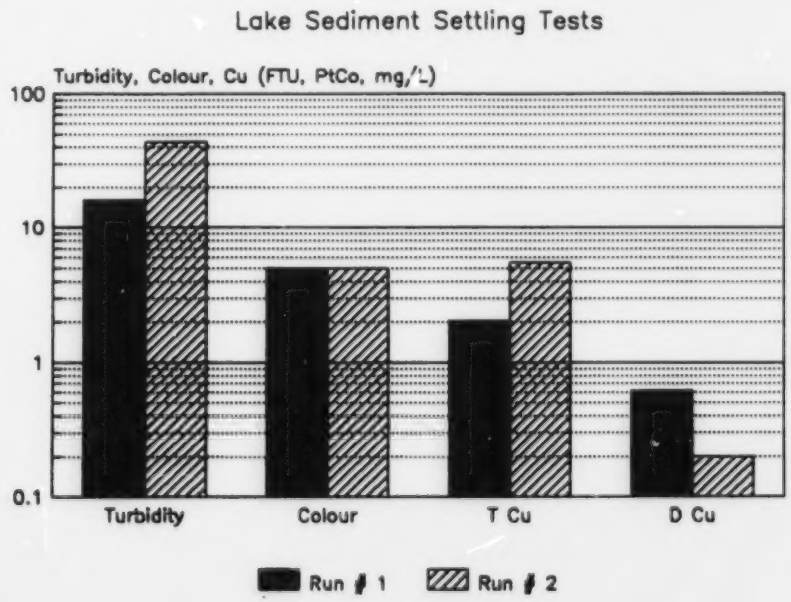

Figure 2.3
Lake Sediment Test #1
Sediments plus $CuSO_4$ & NaOH

colloidal material consisting of humic acids and tannins which may have the ability to stabilize copper as finely dispersed colloids or to complex it in solution.

2.6.2 Lake Sediment Test # 2

2.6.2.1 Purpose

The purpose of this test was to evaluate the formation of colloidal copper in the tailings pond supernatant during natural degradation of cyanide when exposed to lake sediments. This test was conducted to determine whether copper released from the copper cyanide complex during natural degradation would attach to the fine sediments and report as colloidal "dissolved" copper. This test involved a mixed slurry of lake sediment containing copper cyanide and free cyanide.

2.6.2.2 Procedure

The procedures used in this test were as follows:

1) 0.1866 g NaCN was dissolved in 1.5 L deionized/distilled water to generate a solution containing 66 mg/L CN^-.
2) 15 mL of a copper sulphate solution containing 2 mg Cu^{+2}/mL was added to this solution to generate a cyanide solution containing 20 mg/L Cu.
3) 37.5 g of wet lake sediments containing 4.65 g of dry solids was added to the copper cyanide solution and mixed continuously at 400 RPM using a variable speed mixer and 2 inch propeller.
4) the initial slurry pH of 8.48 was not adjusted
5) a 25 mL aliquot was extracted from the vessel filtered through 0.45 μm filter paper, and analyzed for total copper.
6) additional 25 mL aliquots were collected after 5 and 30 days and analyzed for pH, dissolved copper, free cyanide and total cyanide.

2.6.2.3 Results

The initial measured dissolved copper level was 17.4 indicating that a portion of the copper added was adsorbed by the solids. The results of Lake Sediment Test # 2 are presented in Figure 2.4.

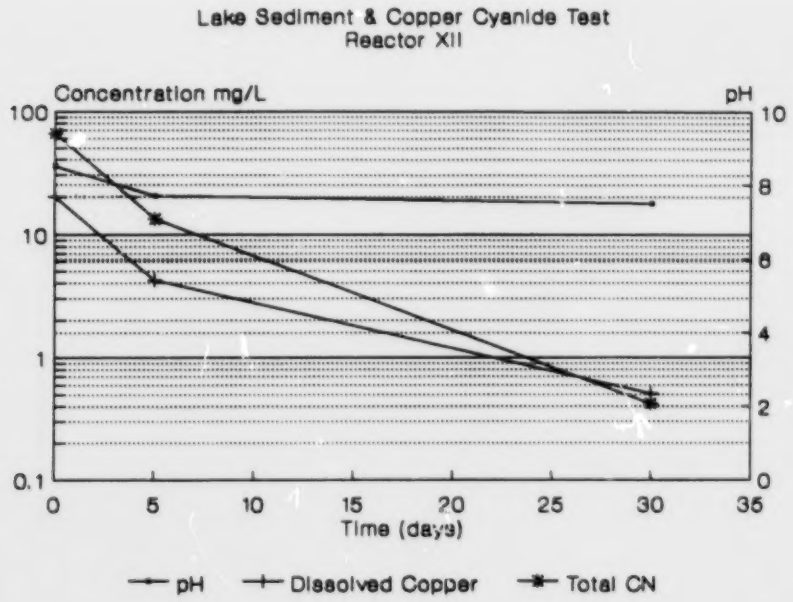

Figure 2.4
Lake Sediment Test # 2
Sediments plus copper cyanide and free cyanide ions

pH dropped from 8.5 to 7.5 during the experiment.

The experiment was complicated by the loss of liquid from splashing and evaporation. The volume had been reduced, from both splashing and evaporation, to 20% of original after 30 days. The total copper concentration of the slurry increased from 17.4 to 36.7 mg/L due to evaporation.

The high degree of mixing and aeration was responsible for a rapid drop in free cyanide levels from a theoretical value of 41.4 to a measured value of 4.8 mg/L after 5 days. The slurry contained no detectable free cyanide after 30 days. Total cyanide followed a similar pattern, dropping from an initial theoretical concentration of 66 mg/L to 13.3 after 5 days and 0.26 mg/L after 30 days.

Dissolved copper levels also followed a similar trend, dropping from a measured initial value of 17.4 mg/L to 4.25 mg/L after 5 days and 0.51 mg/L after 30 days. The dissolved copper readings at 5 days would indicate that the slurry contained 5.2 mg/L of free CN.

This value agrees reasonably well with the measured free cyanide concentration of 4.8 listed above. There was sufficient cyanide present after 5 days to complex all measured dissolved copper as the copper cyanide complex, $Cu(CN)_3^{-2}$.

At 30 days there was sufficient cyanide in solution to dissolve 0.21 mg/L copper assuming the presence of $Cu(CN)_3^{2-}$ or 0.31 mg/L copper assuming copper is complexed as $Cu(CN)_2^{1-}$. Since the measured "dissolved copper" was 0.51 mg/L, the sample did contain some colloidal copper i.e. 0.20 to 0.30 mg/L.

After completion of the tests it was noted that since the amount of mixing and aeration was significantly greater than that encountered in a tailings pond, the results obtained were not indicative of a tailings pond where copper cyanide degrades by natural degradation while in contact with lake sediments. Following review of the results obtained an additional copper cyanide - lake sediment test was conducted. This test is described below in section 6.3.

2.6.3 Lake Sediment Test #3

2.6.3.1 Purpose

The purpose of this test was to evaluate the formation of colloidal copper in the tailings pond supernatant in the absence of cyanide and to provide a basis for comparison with results obtained with the Test # 2.

2.6.3.2 Procedure

The procedure used in this test was identical to Test # 2 except that the addition of NaCN was omitted. However one major difference was that the addition of copper sulfate to the slurry containing lake sediment reduced the pH. This did not occur with Test # 2 since NaCN is a basic salt which neutralized the copper sulfate solution.

After the addition of copper sulfate, the slurry pH was adjusted from 4.9 to 7.5 with 0.8 mL 1N NaOH. However the pH continued to drop with mixing, and an additional 0.4 mL 1N NaOH was required to adjust the pH to 7.5.

A 25 mL sample aliquot was extracted from the vessel, filtered through 0.45 μm filter paper, and analyzed for total copper.

2.6.3.3 Results

The results of Lake Sediment Test # 3 are presented in Figure 2.5.

Fluctuations in pH were observed at the beginning of the test. Repeated additions of sodium hydroxide were needed to maintain the pH above 7. Additions were performed

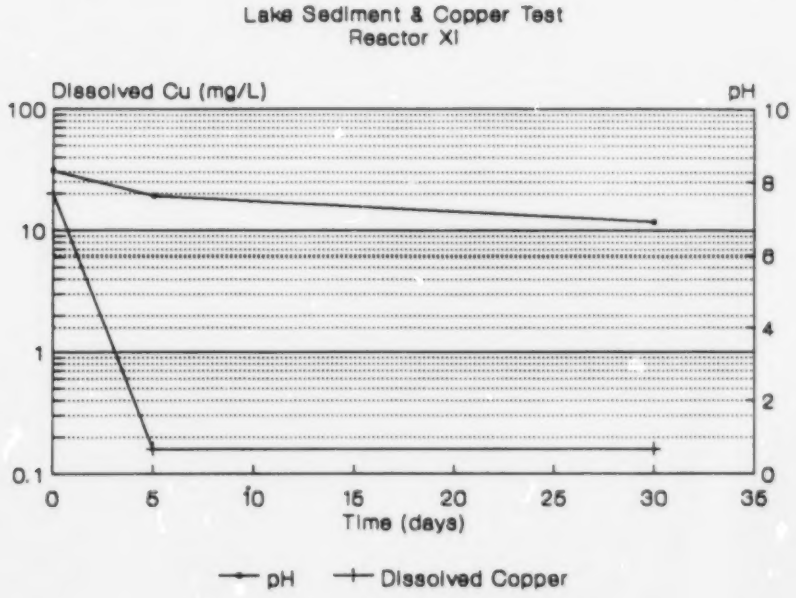

Figure 2.5
Lake Sediment Test # 3

once a day for one week. The pH was stabilized at approximately 7.5. In total 1.2 ml of 1N NaOH was added to the reactor over the first week.

Dissolved copper, starting at 20 mg/L, fell quickly. The dissolved copper levels had dropped almost to the final level by the third day. The final dissolved copper levels were 0.16 mg/L indicating. At the solution of 6.9, this concentration of copper could be present in solution as copper hydroxide. Therefore it is concluded that the test was not successful in producing any significant amount colloidal copper reporting as "dissolved" copper.

2.6.4 Lake Sediment Test # 4

2.6.4.1 Purpose

The purpose of this test was to evaluate the formation of colloidal copper during natural degradation of cyanide when exposed to lake sediments. This test was a repeat of Test # 2 with these modifications.

1) The slurry was mixed with a magnetic stirrer and used aeration to reduce the degree of agitation compared to Test # 2.

2) The quantity of NaCN and copper sulfate added was changed to produce an initial solution where all the cyanide present was theoretically complexed with cyanide and there was no free cyanide present.

2.6.4.2 Procedure

The procedures used in this test were similar to Test # 2.

1) 0.2746 g NaCN was dissolved in 2.2 L deionized/distilled water to generate a solution containing 66 mg/L CN^-.

2) 40 mL of a copper sulphate solution containing 2 mg Cu^{+2}/mL was added to this solution to generate a cyanide solution containing 36 mg/L Cu.

3) 150 mL g of wet lake sediments containing 18.6 g of dry solids was added to the copper cyanide solution and mixed using a magnetic stirrer and diffused air.

4) the initial slurry pH of 6.48 was adjusted to 7.23 with NaOH.

5) an initial 25 mL aliquot was extracted from the vessel and analyzed for total and dissolved copper and cyanide.

6) two 25 mL samples of the slurry were collected after 3, 7 and 17 days and analyzed for pH as well as total and dissolved copper and cyanide. Volume loss due to sample collection and evaporation was made up deionized/distilled water.

2.6.4.3 Results

The initial slurry contained 34.3 mg/L dissolved Cu and 39.3 mg/L CN for a CN:Cu of 1.1. This is between the CN:CU ratio of 1.23 for $Cu(CN)_3^{-2}$ and 0.82 for $Cu(CN)_2^{-1}$ indicating that the slurry did not contain any free cyanide. The results for Lake Sediment Test # 4 are presented in Figure 2.6. The total cyanide concentration of the slurry dropped during the test from 39.3 to 6.9 mg/L while the cyanide concentration in the filtrate after 0.45 μm filtration dropped from 39.3 to 0.09 mg/L. The concentration of copper in the filtrate dropped in parallel to the cyanide concentration i.e. from 34.3 to 0.38 mg/L. These results indicate that the copper cyanide complex may be preferentially adsorbed or attached to the lake sediments solids similar to activated carbon. At 17 days the cyanide concentration in solution was 2 orders of magnitude less than the concentration on the slurry. This behaviour has a significant impact on the use of natural degradation processes in tailings pond containing organic sediments.

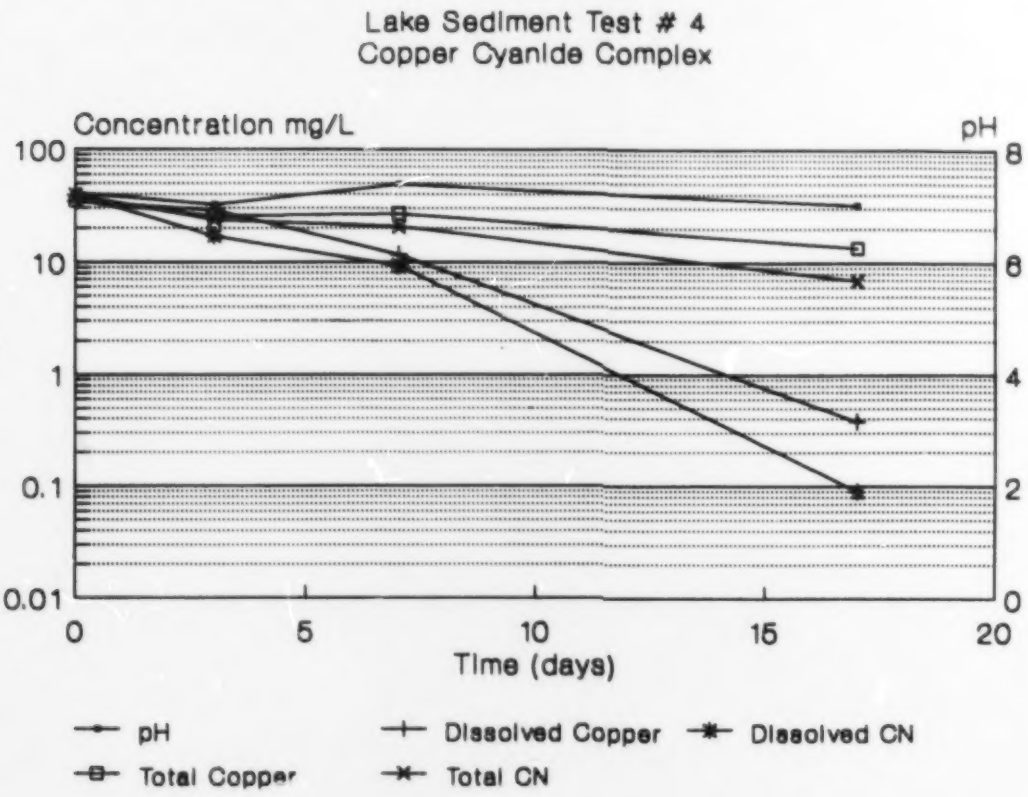

Figure 2.6
Lake Sediment Test # 4

2.7 Natural Degradation Tests

The purpose of the natural degradation studies was to evaluate the formation of soluble and colloidal metal complexes during the natural degradation process. The focus of this work was to generate simulated reclaim samples where copper was present in "apparent" solution at concentrations above that predicted by theoretical solubility.

2.7.1 Procedures

2.7.1.1 Pre-Aeration

The purpose of aerating the sample was to strip a portion of the free cyanide present and accelerate the natural degradation process. A trial aeration test was performed to determine aeration time required. Free cyanide was determined by silver nitrate titration. The air flow rate was 20 mL/min. A 2 L sample of mill tailings filtrate was used for the test.

2.7.1.2 Results

The pH dropped linearly for a 20 hour period and then stabilized near 8.0. Free cyanide also dropped rapidly. Free cyanide was about 4 mg/L after 120 hours of aeration. The results of this test are plotted in Figure 2.7.

2.7.2 Description of Test Conditions

The mill tailings filtrate sample was mixed and divided into eight 2.5 L portions.

Eight vessels were set-up as follows.

I Tailings Filtrate without pre-aeration

II Tailings Filtrate with pre-aeration

III Tailings Filtrate plus Sulphide without pre-aeration

IV Tailings Filtrate plus Soda Ash with pre-aeration

V Tailings Filtrate plus Phosphate with pre-aeration

VI Tailings Filtrate plus Lake Sediments with pre-aeration

VII Tailings Filtrate plus Lake Sediments and Soda Ash with pre-aeration

VIII Tailings Filtrate plus Lake Sediments and Phosphate with pre-aeration

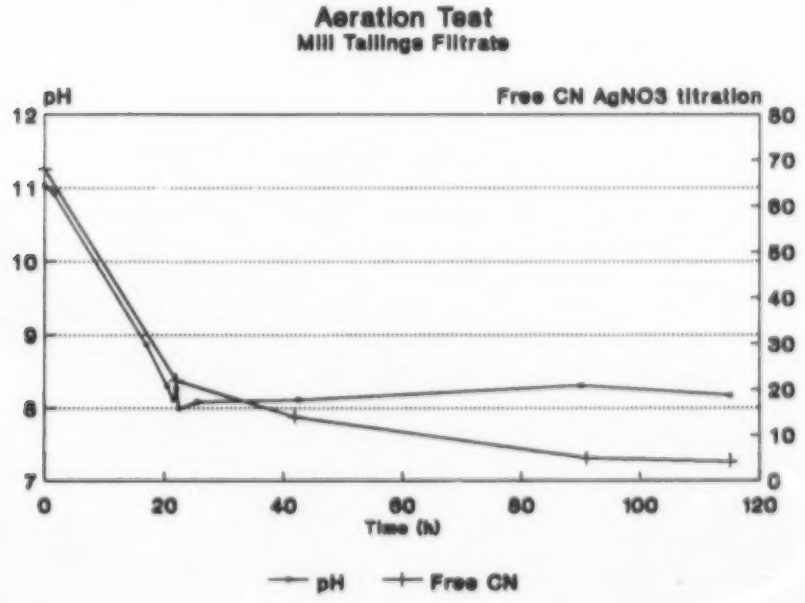

Figure 2.7
Aeration Test Results

Vessel I was left untreated. Vessel II was aerated for 48 hr. Vessel III was treated with 0.4682 g sodium sulphide ($Na_2S \cdot 9H_2O$) to generate a solution containing 25 mg/L S^{2-}. This vessel was not pre-aerated so as to control the oxidation of sulphide present. The fourth vessel (IV) was treated with 0.6623 Na_2CO_3 to yield a solution containing 150 mg/L CO_3^{2-}. This vessel was also aerated. The fifth vessel (V) was treated with 32.5 mL of 0.5% $Na_2HPO_4 \cdot 2H_2O$ solution to generate a solution containing 10 mg/L phosphate as P. This vessel was also aerated at the start of the experiment.

The last three vessels contained screened lake sediments. The same solids concentration as in the Lake Sediment tests was used. 7.5 L of mill tailings filtrate was mixed with wet sediments to generate a slurry containing 3000 mg/L TSS. This combined sample was screened to remove large particles and divided equally between vessels VI, VII and VIII. Vessels VII and VIII were treated with soda ash and phosphate at the same concentrations as Vessels IV and V. All Lake Sediment samples were aerated.

Initial pH of the mill tailings filtrate was 11.02. Aeration was set at about 12 mL/min in all vessels. A 40 hour aeration period was chosen to strip free cyanide and reduce pH.

pH and free cyanide were monitored daily during the aeration period and weekly subsequent to the aeration period.

2.7.3 Results

Cyanide and copper dropped to low levels in all the samples containing lake sediments. The rest of the vessels still contained measurable amounts of cyanide after 121 days of testing. Analysis of the copper and cyanide data after 121 days indicates that all vessels contained "dissolved" copper that is not complexed with cyanide, where dissolved copper is defined by 0.45 μm filtration. Vessels VI VII and VIII contained 0.41, 1.24 and 0.56 mg/L of "dissolved" copper above that amount theoretically present due to cyanide complexation as $Cu(CN)_3^{2-}$.

The initial pH drop was rapid followed by stabilization in the 8.5 to 8.7 range after 20 days and then a long slow decline. The pH readings collected during the natural degradation tests are plotted in Figure 2.8.

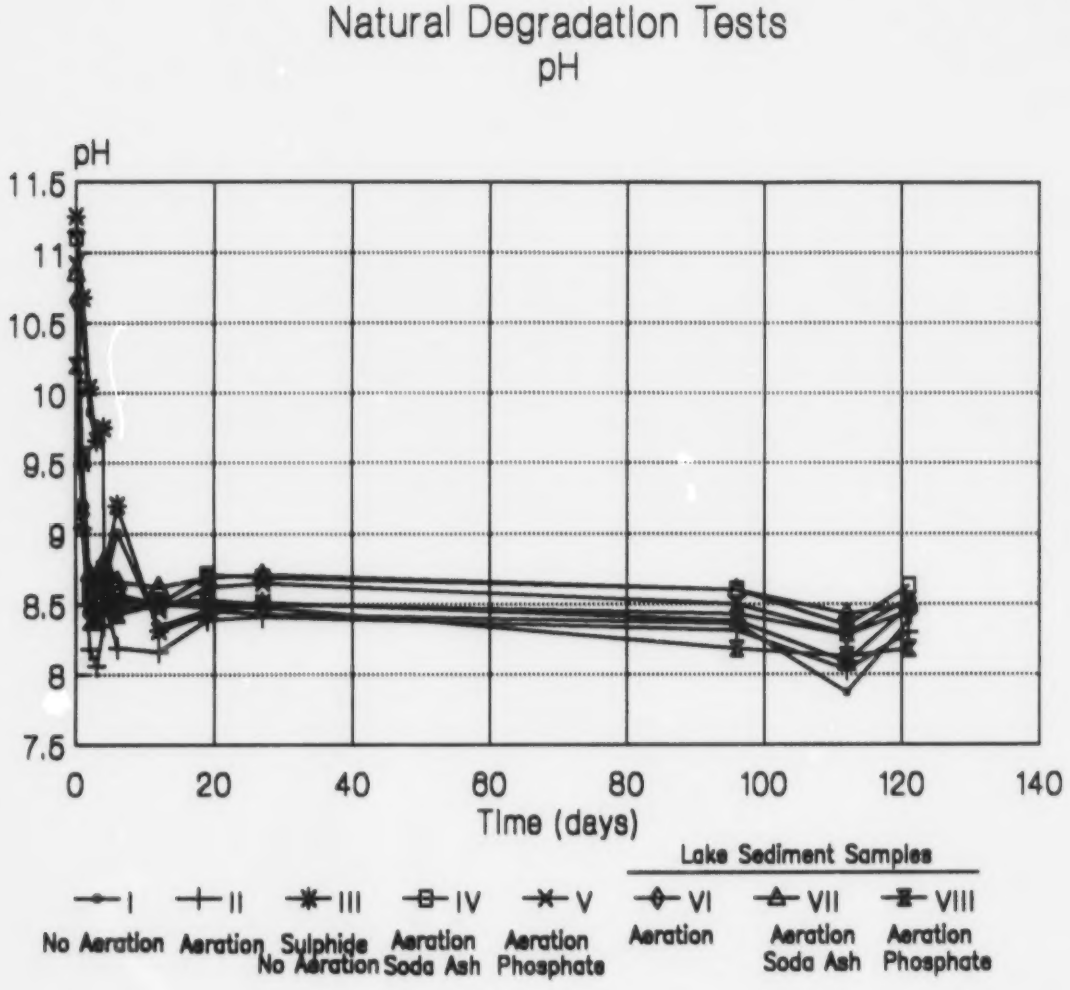

Figure 2.8
pH during Natural Degradation Tests

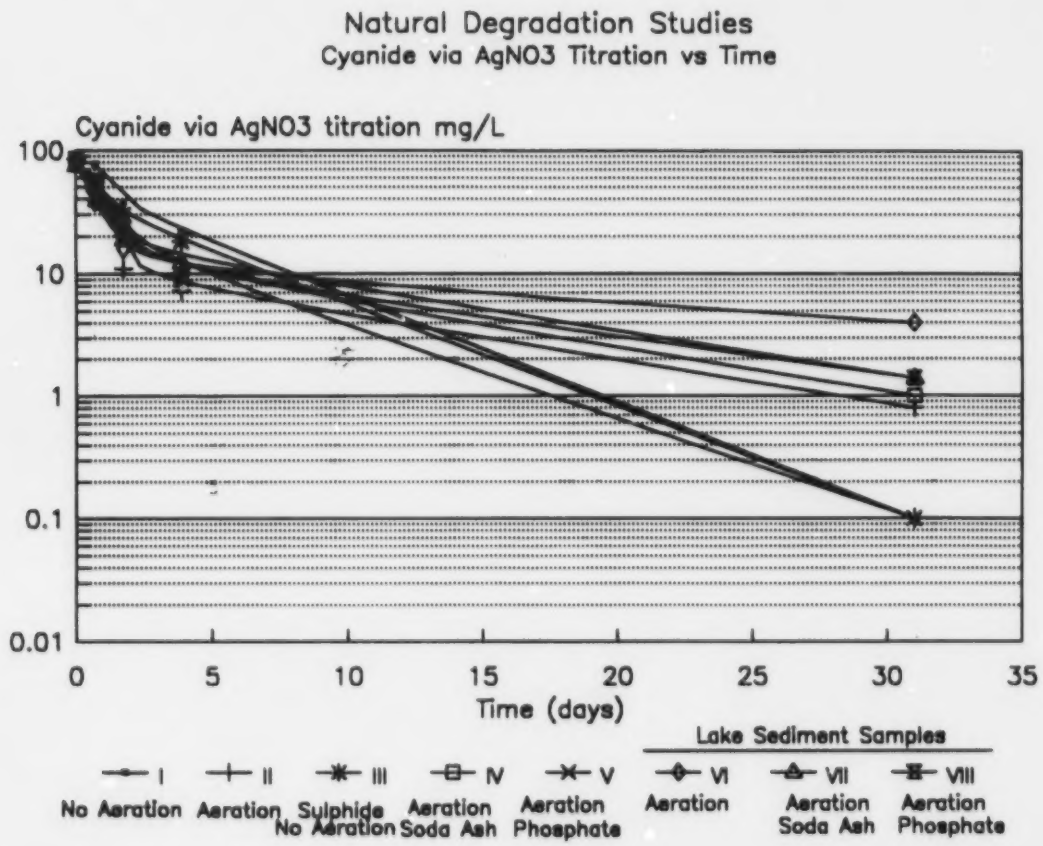

Figure 2.9
Free Cyanide

Free cyanide measurements were made using titration with silver nitrate during the first 40 days. These results are plotted in Figure 2.9.

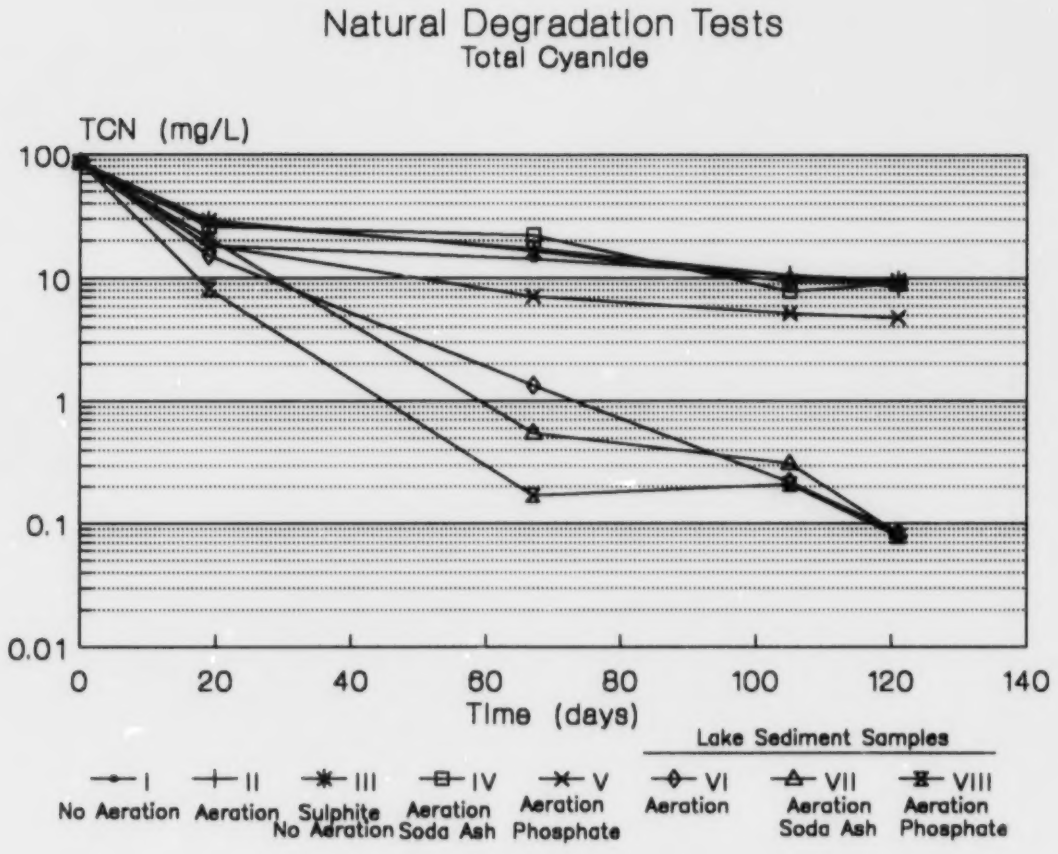

Figure 2.10
Total Cyanide

The TCN and Total Copper data are plotted in Figures 2.10 and 2.11. After 121 days the TCN had dropped to between 9.55 and 4.79 in Vessels I through V which did not contain Lake Sediments and between 0.085 and 0.078 mg/L in Vessels VI through VIII which did. The copper results closely paralleled the cyanide results. Supernatant turbidity data collected during the tests is plotted in Figure 2.12. Turbidity in the supernatants dropped rapidly during the first 12 days and then declined at a slow rate to Day 112. Supernatant turbidity was an order of magnitude higher in the Vessels which contained Lake Sediments than the Vessels without Sediments.

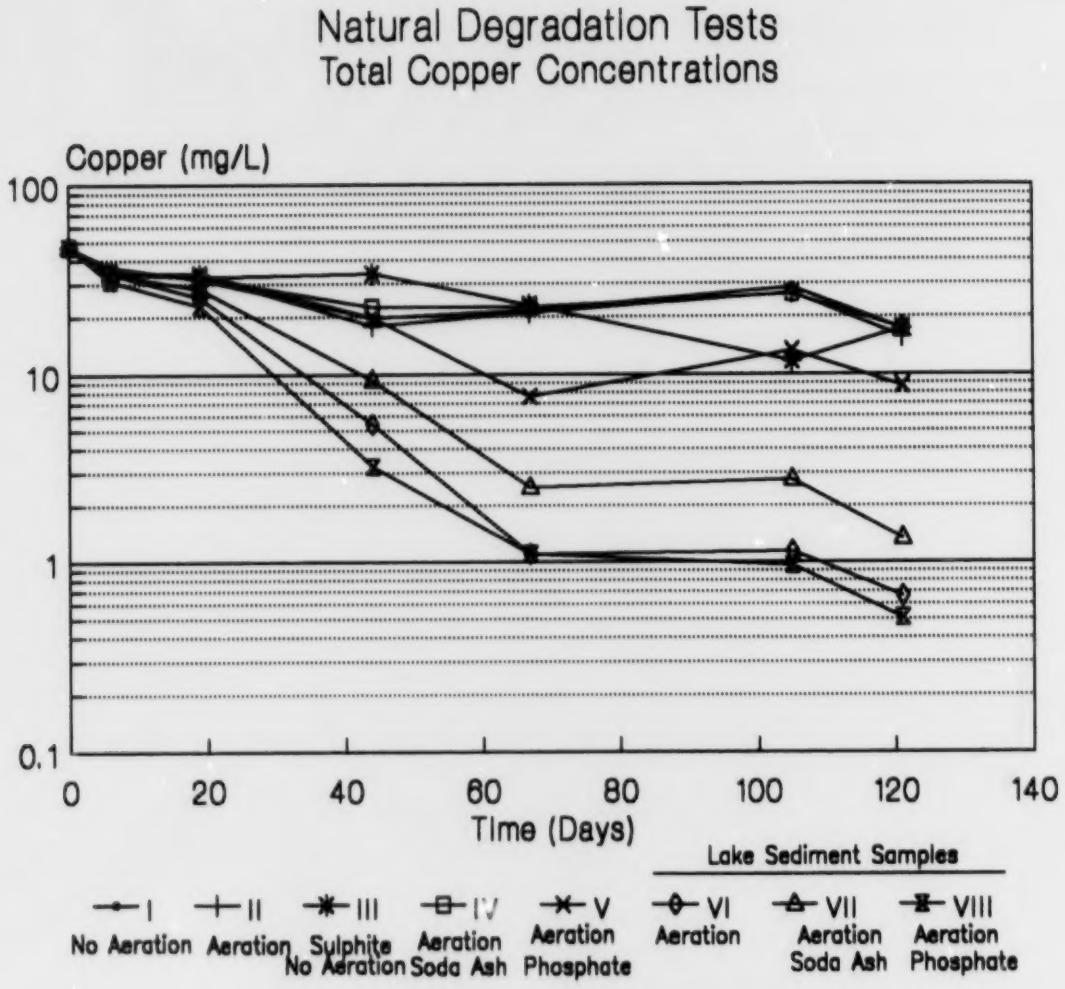

Figure 2.11
Total Copper

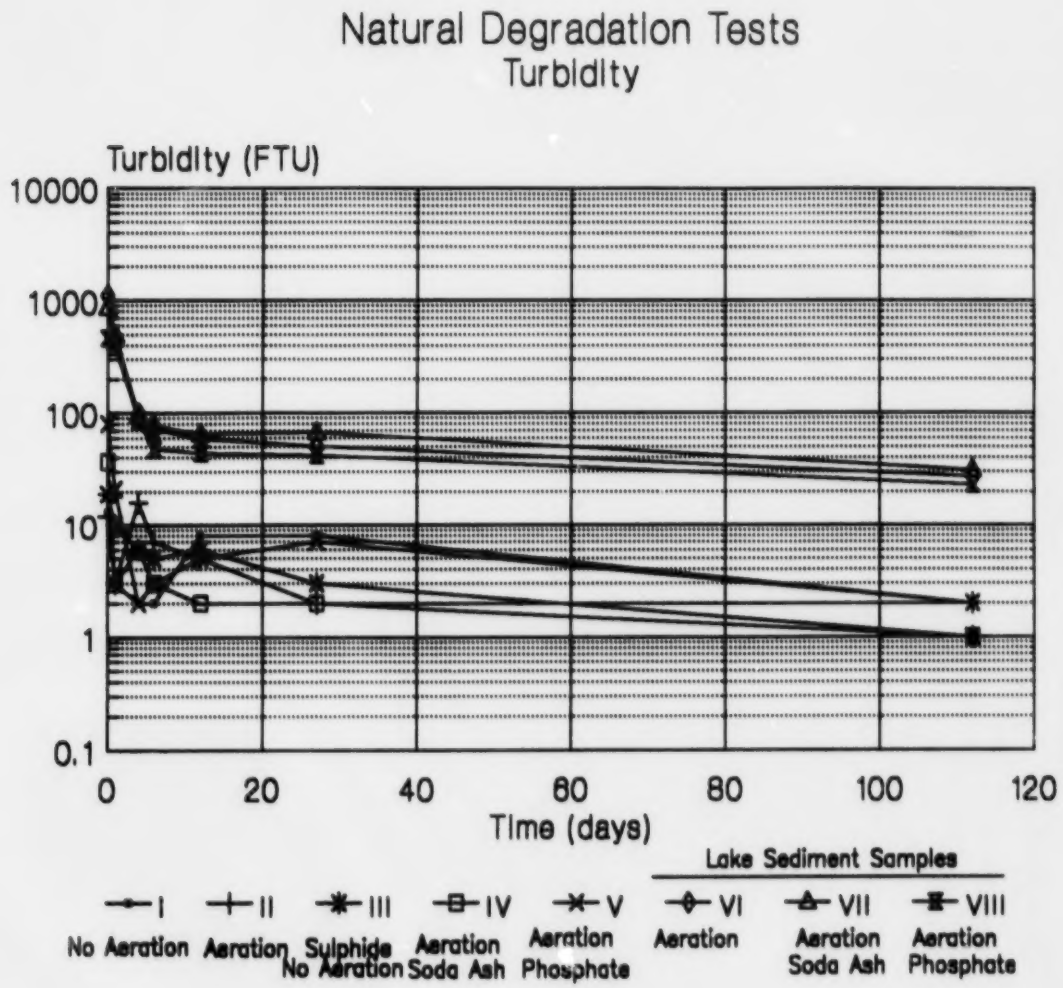

Figure 2.12
Turbidity

2.7.4 Treatment of Natural Degradation Test Products

2.7.4.1 Purpose

At the termination of the natural degradation tests the supernatant from each vessel was treated using ferric sulfate and soda ash to remove "colloidal" material. The purpose of this test was to evaluate the form of copper present. The use of ferric sulfate and soda ash was selected to coagulate the sample since this combination produced the lowest total and dissolved copper levels in the coagulation tests conducted on reclaim water (see Section 5.0). The basic premise of this test was to remove any "dissolved" copper present as a colloid by coagulation. The test is qualitative since $Fe(OH)_3$ precipitation may have removed some copper in solution by adsorption while the use of soda ash may have removed some copper by carbonate precipitation.

2.7.4.2 Procedures

1 L aliquots of supernatant from each vessel were treated with a solution of ferric sulphate containing 37 mg/L Fe^{3+}. Vessels I through III were treated with 2 mL of the ferric solution while Vessels IV through VIII used 3 mL. Corresponding Fe^{3+} dosages were 74 and 111 mg/L respectively. Sample pH, which dropped after ferric sulphate addition was adjusted to the 7.0 - 7.5 range using Na_2CO_3 solution. The quantity of Na_2CO_3 required for Vessels I, II and III was 450 mg/L while the quantity required for Vessels IV through VIII was 575 to 625 mg/L. After addition of soda ash, each sample was flocculated using 2 ppm of Percol 156. The supernatant after each sample was allowed to settle was filtered through 0.45 μm filter paper. The filtrates were analyzed for TCN, TCu and turbidity.

2.7.4.3 Results

The results of these tests are plotted in Figure 2.13. After 121 days of the natural degradations tests the cyanide levels in Vessels I through V remained above dischargeable levels. Only the three vessels containing Lake Sediments had demonstrated sufficient cyanide degradation to yield a dischargeable effluent.

The "dissolved copper" concentrations (defined by 0.45 μm filtration) in Vessels VI, VII and VIII were 0.66, 1.34 and 0.51 respectively before treatment and 0.096, 0.161 and 0.046 respectively after treatment with ferric sulfate. The cyanide concentrations were 0.085, 0.083 and 0.078 mg/L for respectively for Vessels VI through VIII. The "dissolved" copper concentration before treatment would indicate that the three lake sediments samples contained some copper in apparent solution above the theoretical limit if it is assumed that all the copper is present as copper cyanide complex $Cu(CN)_3^{2-}$. Figure 2.13 also includes CN/Cu mole ratios which have been calculated from the dissolved copper and cyanide concentrations present after treatment. The mole ratios for Vessels I through VI were in the 1.2 - 1.3 range indicating that these samples contained a

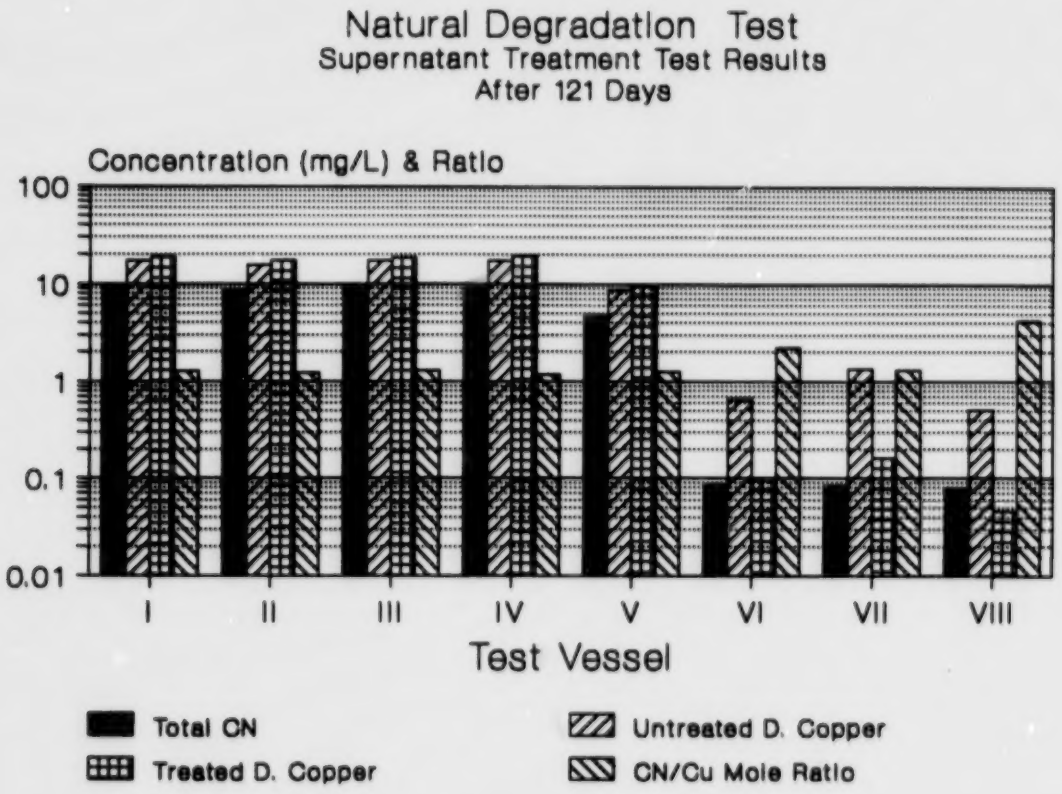

Figure 2.13
Supernatant Treatment Test Results

considerable amount of "dissolved" copper above that explained by complexation as $Cu(CN)_2^{1-}$. Vessels VI, VII and VIII had molar ratios of 2.22, 1.3 and 4.25 respectively. These results indicate that Vessel VII contained excess "dissolved" copper while Vessels VI and VIII did not. The use of molar ratio to assess the behaviour of copper in the last three vessels may not be valid due to the potential for error in the cyanide and copper analyses at low concentrations.

2.7.5 Enumeration of Copper-Cyanide Degraders

Samples of supernatant and sediments from the natural degradation tests and the Lake Sediments Test #4 were collected and examined to enumerate the concentration and morphology of organisms capable of degrading the copper cyanide complex. The results of the microbiological tests are provided in Appendix B. The test procedures involved collection and serial dilution of inoculum from six different sources followed by plating on a special media that utilized copper cyanide as the sole nitrogen source. The cyanide concentration in the media was approximately 145 mg/L and the dissolved copper concentration was 117 mg/L (equivalent to the $Cu(CN)_3^{-2}$ complex). The CN concentration for the stock solution reported in the EVS report is incorrect.

The results indicate that the Vessels with lake sediments contained significant concentrations of copper cyanide degraders. The plates using inoculum from Vessel I did not produce any colonies, indicating that the concentration of cyanide degraders in Vessel I was less than the detection limit of 10^3 MPN/mL. Based on morphology, it was determined that the microorganisms growing on the copper-cyanide media, consisted of a single species of fungus. The fungus appeared to be more concentrated in the sediments than in the water phase. Based on the results of the natural degradation tests and the enumeration work, it is feasible that biological degradation may have been responsible for observed differences between the Vessels with and without lake sediments.

2.8 Conclusions

The conclusions derived from the test program can be summarized as follows:

1) The reclaim sample collected in September 1991 contained approximately 0.29 mg/L "dissolved" copper above that present due to complexation with cyanide as $Cu(CN)_3^{-2}$. Dissolved copper being defined in this case as any metal present in solution or in particulate form that is not removed by filtration through 0.45 μm filter paper. The total copper concentration of this sample was 1.42 mg/L.

2) Natural degradation of copper cyanide complex results in the release of a minor amount of copper that will report as " dissolved copper" when samples are filtered through 0.45μm filter paper.

3) Coagulation of reclaim water with standard coagulants was capable in mosts cases of removing a significant portion of the copper that reported as "dissolved" copper after 0.45 μm filtration.

4) Coagulation with a combination of ferric sulphate and soda ash produced the best results in terms of turbidity, colour, total copper and dissolved copper removal. The dissolved copper concentration after treatment with ferric sulphate and soda ash was 0.02 mg/L compared to a "dissolved" copper concentration before treatment of 0.392 mg/L.

5) The Lake Sediments tests demonstrated the following:

   i) these sediments contain fine particles that settle poorly and some very fine particles that are not removed by 0.45 μm filtration.

   ii) cupric ion will attach to or be stabilized by these sediments and remain either in suspension or as apparent "dissolved" copper in the absence of cyanide.

   iii) the copper cyanide complex can be preferentially adsorbed or attached to lake sediments in a system where the complex is in intimate contact with the sediments.

6) Conclusions from the Natural Degradation tests were as follows:

   i) cyanide degradation rates in samples containing lake sediments were significantly higher than samples without sediments. Biodegradation or adsorption to the sediments may have been responsible for observed differences in the rates.

   ii) reductions in pH in all the vessels were rapid during the first 17 days when the pH dropped from the 10.5 to 11.5 range to the 8.5 to 8.7 range.

   iii) after this initial period, the rate of pH reduction was slow. pH remained above the optimum for natural degradation for a large portion of the time the test was conducted.

   iv) Vessel VIII which contained lake sediments and supplemental phosphate exhibited the highest rate of cyanide degradation yielding a TCN concentration of <0.2 mg/L after 68 days. However the total copper concentration after 68 days was above discharge limits at approximately 1 mg/L. After 121 days, the TCN concentrations in all Vessels containing lake sediments were <0.1 mg/L while total copper remaining in the 0.5 to 1.3 mg/L range.

7) All natural degradation vessels contained "dissolved" copper above the amount theoretically complexed by cyanide as either $Cu(CN)_3^{2-}$ or $Cu(CN)_2^{1-}$. The CN/Cu mole ratios for Vessels I through VI were in the 1.2 - 1.3 range indicating that these samples contained a considerable amount of "dissolved" copper above that explained by complexation as $Cu(CN)_3^{2-}$ or $Cu(CN)_2^{1-}$.

8) The microbiological enumeration tests indicated that the Vessels with lake sediments contained significant concentrations of copper cyanide degraders. The organism appeared to be a single species of fungus. The concentration of this fungus was significantly higher in the sediments than in the water phase. Biological degradation may have been responsible for the higher cyanide degradation rates observed in the natural degradation tests containing lake sediments.

3.0 DISCUSSION AND RECOMMENDATIONS

3.1 Discussion

Gold mill effluent commonly contains appreciable concentrations of soluble copper since copper readily forms stable cyanide complexes such as $Cu(CN)_2^-$ and $Cu(CN)_3^{2-}$.

Natural degradation can remove cyanide and metal cyanide complexes by natural physical/chemical means through prolonged exposure to natural elements. The major cyanide removal mechanisms responsible for natural degradation include:

- pH depression due to CO_2 absorption
- volatilization of hydrogen cyanide gas (HCN),
- dissociation of metal complexes with release of cyanide ion,
- photolysis of iron cyanide, and
- precipitation of metal complexes.

Based on the literature, the primary mechanisms responsible for cyanide removal are neutralization, volatilization and dissociation of metal complexes. However, the testwork conducted as part of this study would indicate that adsorption of metal complexes onto organic matter and biodegradation may also play a significant role in the process.

Gold mill effluents conventionally have a high pH since the cyanidation process uses pH conditions often above 10.5 to control the loss of cyanide during milling. In tailings ponds systems where lime has been used for pH control, the pH of the pond supernatant will drop due to the absorption of carbon dioxide from the air and precipitation of calcium carbonate as follows:

$$CO_2 + Ca(OH)_2 \text{ ======> } CaCO_3\downarrow + H_2O$$

The rate of CO_2 absorption is influenced directly by the degree of contact between the air and the solution. This rate is enhanced by having either a high surface area to pond volume ratio or through natural or mechanical mixing and aeration. pH depression by CO_2 absorption from the air can only occur under ice-free conditions.

Reduction in pH is essential to the natural degradation process since cyanide must be present as HCN to volatilize from solution. The fraction of cyanide present in solution as molecular HCN is dependent on pH. At pH 9.36 the concentrations of HCN and CN^- ion are equal. pH should be below 8.5 to ensure that a substantial percentage of "free cyanide" is present as HCN.

Once pH has dropped, volatilization can occur. The volatilization rate is enhanced by the same circumstances that enhance pH depression. However there are limits to the

rate of volatilization due to the fact that HCN is very soluble in water. This factor becomes quite critical at low cyanide concentrations.

Cyanide forms a variety of metal complexes of varying stability. These metal cyanide complexes equilibrate with cyanide ion in solution. For example with copper:

$Cu(CN)_3^{2-} <====> Cu(CN)_2^{-} + CN^{-} <====> CuCN\downarrow + 2CN^{-}$

Depending on the pH of the solution, the cyanide ion released from the complex can then combine with hydrogen ion to form molecular HCN which volatilizes from solution. As CN^{-} ion is lost from solution due to volatilization of HCN, the $Cu(CN)_3^{2-}$ complex will release additional CN^{-} ion in an attempt to maintain the equilibrium. The dissociation rate for $Cu(CN)_3^{2-}$ is slow with a reported half life of 5.3 days @ pH 7.0 and 20°C (Simovic, 1989). The rate of dissociation decreases with a decrease in temperature and decreases with an increase in pH. At pH 10.5 and 4°C the half life for the $Cu(CN)_3^{2-}$ complex increases to 1.1 year based on the literature data.

In the absence of factors such as adsorption to organic matter and biodegradation, the rate of dissociation of the metal complexes is generally the rate controlling step in the natural degradation process.

The behaviour of the natural degradation tests for the samples without lake sediments agreed with predictions based on the above theory. Conversely the behaviour of the samples that included lake sediments do not. In all cases, however the natural degradation process itself appears to release some copper into solution/suspension that will report as the "dissolved" form above that explained by complexation with cyanide.

The behaviour of copper as demonstrated by the testwork results has an number of implications in the application of the natural degradation process to treat gold mill effluent containing copper. These implications are reflected in the recommendations listed below.

Simovic, L. and W.J.Snodgrass, " Tailings Pond Design for Cyanide Control at Gold Mills Using Natural Degradation" Gold Mining Effluent Treatment Seminar Proceedings, Feb 15-16,1989 Vancouver, B.C. and Mar 22-23, 1989 Mississauga, Ontario

3.2 Recommendations

1. Gold mills should be operated to minimize both cyanide and lime consumption to assist the natural degradation process and ultimately control the discharge of copper in the effluent.

   Minimizing cyanide has two benefits, i) reductions in the amount of copper extracted from the ore during cyanidation and ii) reductions in the amount of cyanide that must volatilize from the pond in order to comply with discharge limits. Minimizing lime consumption benefits the natural degradation process by reducing the time required for CO_2 adsorption to reduce pH such that volatilization of HCN is optimized. This in turn will increase the time available for copper to precipitate from solution after cyanide has been removed by volatilization.

2. In cases where the natural rate of neutralization by CO_2 adsorption is inadequate to achieve complete removal of cyanide and copper, the addition of acid to final mill tailings should be considered.

   The addition of acid would achieve two goals; i) the pond pH could be at the optimum pH for volatilization of HCN as soon as the ice cover melts in the spring and, ii) a lower pH in the pond would enhance the dissociation rate of $Cu(CN)_3^{2-}$ by minimizing the concentration of CN^- in solution and potentially precipitating some copper as CuCN during the winter. For safety reasons it would likely be necessary to add the acid directly to the tailings line downstream of the mill. In addition a pH monitoring and control system would likely be required to control acid dosage and prevent problems from the solubilization of metals at low pH.

3. The presence of organic matter such as natural lake sediments should enhance the removal of cyanide in a tailings pond environment. Conversely the presence of fine colloidal solids in the pond supernatant could increase the concentration of copper in the tailings pond O/F. However based on the net benefit of reducing cyanide concentrations quickly, it is recommended that sediments not be removed prior to converting an existing lake to a tailings pond. A site specific evaluation should be conducted for each case to determine whether the benefit of rapid cyanide degradation outweighs any negative effect due to the stabilization of copper by organic colloids in the sediments.

4. Coagulation processes can be used to remove colloidal copper from reclaim water and produce dischargeable effluent assuming cyanide has been removed by natural degradation. The treatment of excess reclaim water could be conducted either in a separate treatment system in the mill or in conjunction with a primary thickener. The validity of this last option will depend on where NaCN is added in the mill and on whether excess primary thickener O/F meets the discharge standards (primarily for pH, TSS and cyanide).

Appendix A
Analytical Results for Initial Samples

ASL

CHEMICAL ANALYSIS REPORT

Date: Oct. 10, 1991

ASL File No. 8239B

Report On: Water and Soil Analysis

Report To: Bion Research Inc.
9141 Shaughnessy Street
Vancouver, BC
V6P 6R4

Attention: Mr. Tom Higgs

Date Received: Sep. 16, 1991

METHODOLOGY

Sediment Analysis

Metals

These analyses are carried out using procedures that are consistent with the requirements of the appropriate regulatory agencies and adapted from U.S. EPA Method 3050 (Publ. # SW-846, 3rd ed., Washington, DC 20460). The procedures involve a digestion using a combination of nitric and hydrochloric acids. The resulting extract is bulked to volume with deionized/distilled water. The digested portion is then analysed by atomic emission spectrophotometry (ICP). Specific details are available upon request.

PLEASE NOTE (When the following elements are reported):

Aluminum, barium, calcium, chromium, iron, manganese molybdenum and vanadium are often associated, to some extent, with the silicate matrix of the sediment. Because of this, the recoveries of these elements may be low using the specified digestion. From an environmental standpoint, this is not a problem since the "available" metals are usually the fraction of concern.

Total Organic Carbon

This analysis is carried out by Leco induction procedures using an IR detector. The procedures involve a carbonate analysis and a total carbon analysis. The difference in carbon values is reported as Total Organic Carbon.

Water Analysis

These analyses are carried out in accordance with procedures described in "Standard Methods for the Examination of Water and Wastewater" 17th Edition published by the American Public Health Association, 1989. Specific details are available on request.

ASL ANALYTICAL SERVICE LABORATORIES LTD.

Brent A. Makelki B.Sc.
Project Chemist

Eda Parreno B.Sc.
Project Chemist

ASL

RESULTS OF ANALYSIS - Sediment/Soil

File No. 8239B
Page 3

Parameter			Sediment (DWB)	Sediment (DWB) Dup.
Total Metals				
Aluminum	T-Al	%	1.30	1.38
Antimony	T-Sb		<25	<25
Arsenic	T-As		<25	<25
Barium	T-Ba		100	100
Beryllium	T-Be		<0.5	<0.5
Bismuth	T-Bi		<10	<10
Cadmium	T-Cd		<2.0	<2.0
Calcium	T-Ca	%	0.914	0.843
Chromium	T-Cr		47.9	48.1
Cobalt	T-Co		14.3	12.4
Copper	T-Cu		64.5	63.8
Iron	T-Fe	%	1.30	1.23
Lead	T-Pb		85	87
Lithium	T-Li		12.6	14.3
Magnesium	T-Mg	%	0.533	0.537
Manganese	T-Mn		409	400
Molybdenum	T-Mo		<5.0	<5.0
Nickel	T-Ni		32.1	28.7
Phosphorus	T-P	%	0.076	0.077
Potassium	T-K	%	0.15	0.23
Selenium	T-Se		<50	<50
Silver	T-Ag		<2.0	<2.0
Sodium	T-Na	%	0.08	0.08
Tin	T-Sn		<30	<30
Vanadium	T-V		26.9	25.8
Zinc	T-Zn		101	99.3
Organic Parameters				
Total Organic Carbon		C	19.0	-

< = Less than the detection limit indicated.
Sediment results expressed as milligrams per dry kilogram of sample except as noted. % = Percent

ASL

RESULTS OF ANALYSIS - Water

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Parameter			T3	Reclaim	Tailings Filtrate
Physical Tests					
Conductivity	umhos/cm		389	688	2160
Total Dissolved Solids			288	572	1910
pH			5.53	7.64	11.4
Total Suspended Solids			<1	389	5
Dissolved Anions					
Alkalinity	CaCO3		97.6	172	410
Chloride	Cl		5.9	8.3	396
Sulphate	SO4		44.2	137	311
Sulphite	SO3		1.0	1.0	36.0
Nutrients					
Nitrate Nitrogen		N	1.67	10.8	0.039
Nitrite Nitrogen		N	<0.001	0.042	0.078
Cyanides					
Total Cyanide	CN		0.043	0.123	86.5
Cyanate	CNO		-	<0.5	38.1
Thiocyanate	SCN		-	1.1	103

< = Less than the detection limit indicated.
Results are expressed as milligrams per litre except for pH and Conductivity (umhos/cm).

ASL

RESULTS OF ANALYSIS - Water

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Page 5

Parameter		T3	Reclaim	Tailings Filtrate
Total Metals				
Aluminum	T-Al	0.24	12.8	2.81
Antimony	T-Sb	<0.20	<0.20	<0.20
Arsenic	T-As	<0.20	<0.20	<0.20
Barium	T-Ba	0.012	0.136	0.027
Beryllium	T-Be	<0.005	<0.005	<0.005
Bismuth	T-Bi	<0.10	<0.10	<0.10
Boron	T-B	0.67	0.69	1.97
Cadmium	T-Cd	<0.010	<0.010	0.024
Calcium	T-Ca	6.71	36.3	110
Chromium	T-Cr	<0.015	0.017	<0.015
Cobalt	T-Co	<0.015	0.027	0.038
Copper	T-Cu	0.071	1.42	47.0
Iron	T-Fe	0.394	10.7	0.810
Lead	T-Pb	<0.050	0.543	<0.050
Lithium	T-Li	<0.015	0.021	<0.015
Magnesium	T-Mg	1.49	5.13	0.106
Manganese	T-Mn	<0.005	0.219	<0.005
Molybdenum	T-Mo	<0.030	0.078	0.307
Nickel	T-Ni	<0.020	0.051	0.288
Phosphorus	T-P	<0.30	0.42	0.57
Potassium	T-K	18.3	38.0	108
Selenium	T-Se	<0.20	<0.20	<0.20
Silicon	T-Si	3.62	27.4	5.23
Silver	T-Ag	<0.015	<0.015	<0.015
Sodium	T-Na	76.5	105	256
Strontium	T-Sr	0.033	0.148	0.286
Thallium	T-Tl	<0.10	<0.10	<0.10
Tin	T-Sn	<0.30	<0.30	<0.30
Titanium	T-Ti	<0.010	0.344	<0.010
Tungsten	T-W	<0.10	<0.10	<0.10
Vanadium	T-V	<0.030	<0.030	<0.030
Zinc	T-Zn	0.071	0.123	1.45

< = Less than the detection limit indicated.
Results are expressed as milligrams per litre

ASL

RESULTS OF ANALYSIS - Water

File No. 8239B
Page 6

Parameter		T3	Reclaim	Tailings Filtrate
Dissolved Metals				
Aluminum	D-Al	<0.20	<0.20	2.70
Antimony	D-Sb	<0.20	<0.20	<0.20
Arsenic	D-As	<0.20	<0.20	<0.20
Barium	D-Ba	<0.010	0.018	0.026
Beryllium	D-Be	<0.005	<0.005	<0.005
Bismuth	D-Bi	<0.10	<0.10	<0.10
Boron	D-B	0.12	0.20	1.96
Cadmium	D-Cd	<0.010	<0.010	0.019
Calcium	D-Ca	6.71	36.3	110
Chromium	D-Cr	<0.015	<0.015	<0.015
Cobalt	D-Co	<0.015	0.018	0.035
Copper	D-Cu	0.065	0.392	46.3
Iron	D-Fe	0.219	0.044	0.117
Lead	D-Pb	<0.050	<0.050	<0.050
Lithium	D-Li	<0.015	<0.015	<0.015
Magnesium	D-Mg	1.47	1.43	0.106
Manganese	D-Mn	<0.005	0.062	<0.005
Molybdenum	D-Mo	<0.030	0.077	0.307
Nickel	D-Ni	<0.020	<0.020	0.288
Phosphorus	D-P	<0.30	<0.30	0.57
Potassium	D-K	16.0	28.5	103
Selenium	D-Se	<0.20	<0.20	<0.20
Silicon	D-Si	3.40	5.29	5.23
Silver	D-Ag	<0.015	<0.015	<0.015
Sodium	D-Na	68.7	93.6	256
Strontium	D-Sr	0.033	0.096	0.284
Thallium	D-Tl	<0.10	<0.10	<0.10
Tin	D-Sn	<0.30	<0.30	<0.30
Titanium	D-Ti	<0.010	<0.010	<0.010
Tungsten	D-W	<0.10	<0.10	0.11
Vanadium	D-V	<0.030	<0.030	<0.030
Zinc	D-Zn	0.071	0.008	1.45

< = Less than the detection limit indicated.
Results are expressed as milligrams per litre

Appendix B
Report on Enumeration of Copper-Cyanide Degraders

Environmental Services for Industry and Government

Vancouver Canada
Seattle U.S.A.

ENVIRONMENT CONSULTANTS

Our File: 9/308-02

March 27, 1992

Tom Higgs
#612 - 1200 West Pender St
Vancouver, B.C.
V6E 2S9

Dear Tom:

Re: ENUMERATION OF COPPER-CYANIDE DEGRADERS

Water and sediment samples were collected in sterile glass jars from several reactors to test for the presence of microorganisms capable of degrading copper-cyanide complexes. Samples were preserved at 4°C until analyzed, within three (3) days of collecting them. Samples were diluted serially in sterile buffer, plated and incubated for two weeks at 20°C. A special media was formulated for this test, as no standard methods to enumerate copper-cyanide degraders exist. The medium was designed to have little free copper and to stably maintain the copper-cyanide complexes, so that microorganisms utilizing free cyanide would not grow. The composition of this medium is attached at the end of this report.

Summary of Results:

Sample I.D.	Number of $CuCn_x$-degraders (MPN Index/mL)	Standard Deviation
Water - I	$< 10^3$ MPN/mL	N.A.
Water - VI	1.1×10^5 MPN/mL	9.5×10^4 MPN/mL
Water - VIII	7.9×10^4 MPN/mL	5.0×10^4 MPN/mL
Sediment - VI	3.6×10^6 MPN/mL 4.4×10^8 MPN/dry g	1.5×10^6 MPN/mL
Sediment - VIII	4.2×10^7 MPN/mL 5.4×10^9 MPN/dry g	4.8×10^7 MPN/mL
Sludge - XII	1.1×10^3 MPN/mL	7.1×10^2 MPN/mL

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These results indicate that an organism found is lake sediment is probably responsible for the degradation of copper-cyanide complexes. Based on the morphology of the microorganisms growing on the copper-cyanide medium, a single species of fungus is responsible for copper-cyanide biodegradation.

Yours truly,

EVS CONSULTANTS

André Sobolewski, Ph.D.
Microbiologist

ABS/abs

METHOD FOR ENUMERATION OF COPPER-CYANIDE DEGRADERS

Cyanide-degrading bacteria utilize the cyanide as a source of nitrogen. Medium for enumeration includes a readily metabolizable carbon source, but supplies copper-cyanide as the sole nitrogen source. The medium was custom-made to incorporate a 250 mL solution of copper-cyanide @ 20 mg/L CN per Litre of medium. To minimize the dissociation of copper-cyanide complexes, the medium was formulated to have a pH of 7.5 and a low salt concentration, particularly for phosphate. The medium is poorly buffered under these circumstances (with low carbonate and phosphate), but amount of metabolizable carbon is sufficiently low that this should not be a great problem.

Since nitrogen-fixing bacteria could also grow on this medium and be falsely scored as copper-cyanide degraders, a check was conducted to confirm the absence of growth on medium lacking copper-cyanide as a nitrogen source. No nitrogen-fixing bacteria grew on this medium.

Medium composition, per Liter:

INGREDIENT	AMOUNT ADDED	FINAL CONCENTRATION
Succinate	270 mg	1 mM
$NaHCO_3$	34 mg	0.4 mM
KH_2PO_4	1.2 mg|	Produces a
Na_2HPO_4	13 mg |	0.1 mM PO_4 concentration
KCl	5 mg	67 μM
$MgSO_4$	1 mg	8.3 μM
$CaCl_2H_2O$	1 mg	7 μM
Agar, Bacteriological	10 g	

Only UltraPure MilliQ water was used to make this medium. The medium was prepared with 750 mL water (pH measured @ 7.5) and was autoclaved at 15 psi for 15 minutes. After autoclaving and partially cooling, 100 μL each of Trace Element solution and Vitamin solution were added (See below). Finally, 250 mL of filter-sterilized copper-cyanide solution (as Cu^1 and Cu^2) was added. The medium was dispensed immediately afterward to Petri plates and it solidified immediately.

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VITAMIN AND TRACE ELEMENT SOLUTIONS ADDED TO BASAL MEDIUM

VITAMINS

Biotin	1 mg
p-aminobenzoic acid	5 mg
B_{12}	5 mg
Thiamin	10 mg

Prepare above in 1 L deionized water, filter-sterilize; add 1 mL to 1 Litre basal medium.

TRACE ELEMENTS

HCl, (25%)	6.5 mL
$FeCl_2.4H_2O$	1.5 g

Dissolve iron in HCl, then dilute in:

Deionized water	993 mL

Follow with addition of:

$CuCl_2.2H_2O$	15 mg
$Na_2MoO_4.2H_2O$	25 mg
$NiCl_2.6H_2O$	25 mg
H_3BO_3	60 mg
$ZnCl_2$	70 mg
$MnCl_2.4H_2O$	100 mg
$CoCl_2.6H_2O$	120 mg

Filter-sterilize this solution; add 1 mL to 1 Litre basal medium.